

ACHIEVING DESIGN TARGET THROUGH STOCHASTIC ANALYSIS

Tsuyoshi Yasuki

Atsushi Okamoto

Masaaki Okamoto

Toyota Motor Corporation

Japan

Paper Number 547

ABSTRACT

This paper describes numerical techniques for minimizing both average and nominal variation of HIC(d) calculated by FMVSS201 FE analysis, while a traditional deterministic FE analysis with nominal input data can minimize only the nominal HIC(d).

Importance of controlling the nominal variation of HIC(d) for achieving design target by impact simulations was discussed in this paper.

INTRODUCTION

Impact simulation by FE analysis has become a popular vehicle developing method. Deterministic FE analysis with the nominal input data has been used for exploring design directions for frontal crash, side impact, FMVSS201 analysis and so on for more than fifteen years. However, actual test vehicle has nominal variations in shape, thickness and material properties of sheet metal and plastic interior trim so-called re-productability. Also, actual test results have nominal variations of test conditions such as impact velocities, angles, and positions so called repeatability.

Authors think that the re-productability and repeatability should be taken account for in the impact simulations by FE analysis for achieving the design target in actual tests. Authors newly introduced reliability coefficient to minimize the average and nominal variation of HIC(d) simultaneously. A relationship between the average of HIC(d) and the nominal variation of HIC(d) was investigated by using the reliability coefficient.

FE MODEL DESCRIPTION

FE models includes a dummy model of the occupant's head known as the Free Motion Head(here after FMH) , interior trim materials, plastic ribs, and body model are developed for the FMVSS201 simulation(Fig.1). Moreover, material models are developed taking into consideration plastic ribs substantial dependence on strain rate and substantial reduction of in the Young's modulus due to fracture of internal structure in greater strain range. Detail of the FE model is described in the reference [1] and [2].

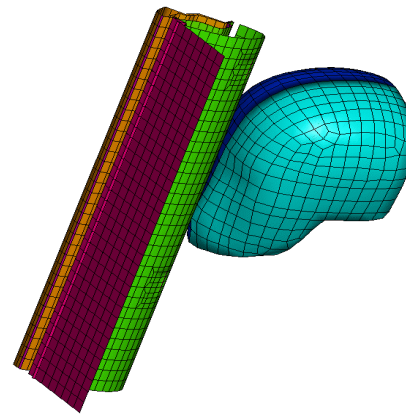


Fig. 1 FE model

Validation of the FMVSS201 Analysis Model

We developed a model shown in Fig.1 and made a validation of the FE model against test results. FE analysis results show fairly good correlations with testing with regard to acceleration (Fig. 2). FE analysis results shows larger acceleration than the test, because the FE model does not take an account of flexibility of body in white.

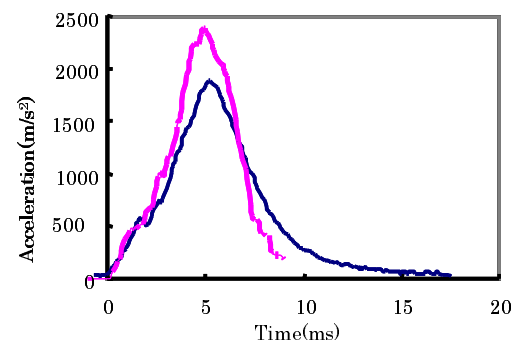


Fig. 2 Comparison of acceleration (Red line indicates FE analysis and blue line indicates test result.)

Deterministic FE analysis with the nominal input data indicates that HIC(d) of original FE model is 0.842 in the normalized form. Hereafter, HIC(d) will be indicated in the normalized form.

ESTIMATION OF AVERAGE AND NOMINAL VARIATION OF HIC(d)

The reproductability and repeatability in the actual tests are modeled as a statistic distribution of design variables and boundary conditions in estimating average and nominal variation of HIC(d). The estimation process consists of three steps. The first step is generating perturbed FE models including variations of design variables and boundary conditions, the second step is doing impact FE analyses for each perturbed FE models, and the last

step is analyzing frequency distribution of HIC(d) (Fig.3).

The perturbed FE models have five design variables and five boundary conditions (Table2, Fig. 4). The perturbed FE models are generated by Latin Hypercube method with statistic distribution of design variables and boundary conditions. 82 cases are sampled.

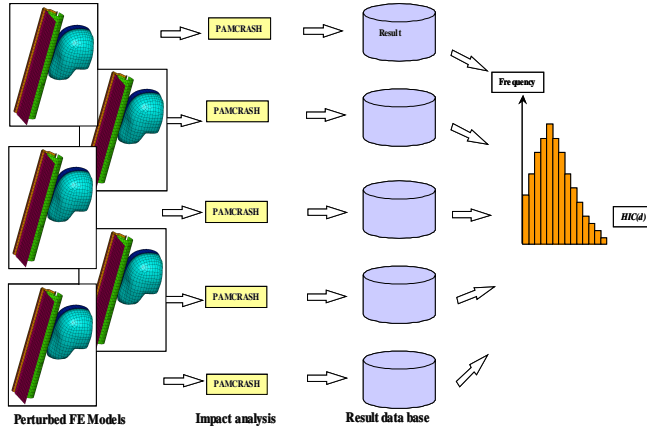


Fig. 3 Estimation process of Average and normal variation

Table 1 Types of distribution for boundary conditions and design variables

NO.	Boudary contitions / Design variables	Type of Distribution
1	Impact peed	Normal
2	Impact posiiton in orizontal direction	Normal
3	Impact posiiton in verticaldirection	Triangle
4	Imact angle in horizontal plane	Normal
5	Imact angle in vertical plane	Normal
6	Horizontal rib #1	Normal
7	Vertical rib #1	Normal
8	Vertical rib #2	Normal
9	Vertical rib #3	Normal
10	Yielding point of rib	Constant

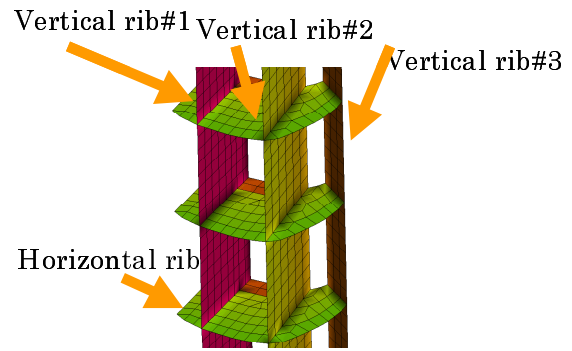


Fig. 4 Design variables

The 82 perturbed FE models are calculated by PAM-CRASH finite element code. The 82 analysis results are summarized and frequency distribution of HIC(d) was obtained (Fig. 5). Nominal, average and nominal variation of HIC(d) by original FE model are 0.842, 0.868 and 0.039 respectively.

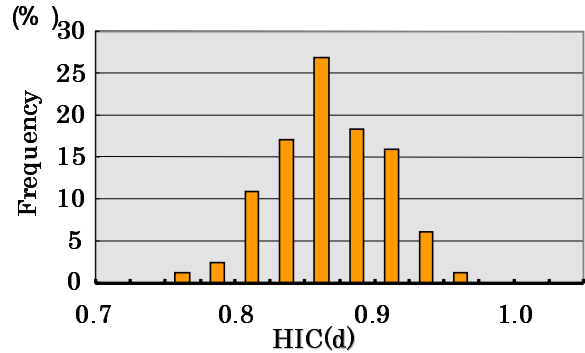


Fig. 5 Frequency distribution of HIC(d)

OPTIMIZATION OF NOMINAL HIC(d)

A purpose of establishing the impact simulation is to minimize nominal HIC(d). Response surface method is one of numerical optimization method applicable to nonlinear problems. Authors applied the response surface method to minimize nominal HIC(d). The 82 cases of finite element results described in the previous chapter were curve fitted to a response surface (Equation 1).

$$\tilde{y} = f(x) = a_0 + a_1 x + a_2 x^2 + \dots + a_n x^n \quad (1)$$

The response surface indicates a close correlation with 82 cases of finite element results (Fig. 6).

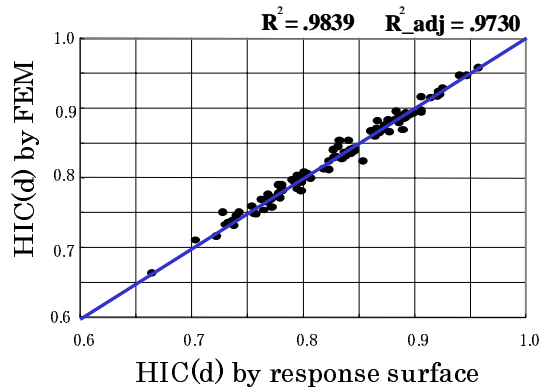


Fig. 6 Correlation of response surface

HIC(d) is minimized on the response surface by selecting four design variables constraining mass of the ribs are constant. The design variables are thickness of a vertical rib and three horizontal ribs (Fig. 7,8,9).

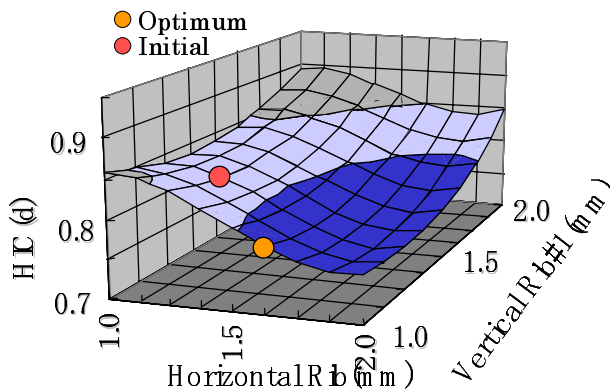


Fig. 7 Response surface (#1)

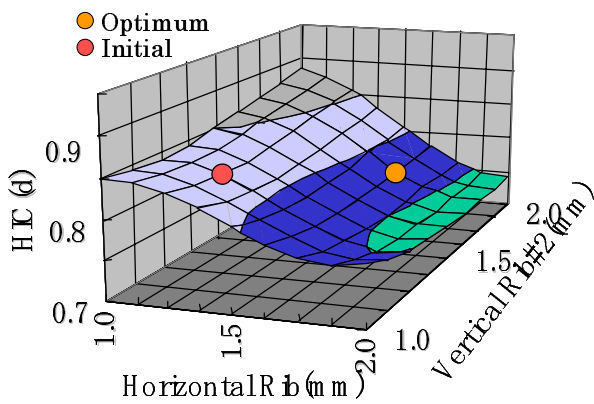


Fig. 8 Response surface (#2)

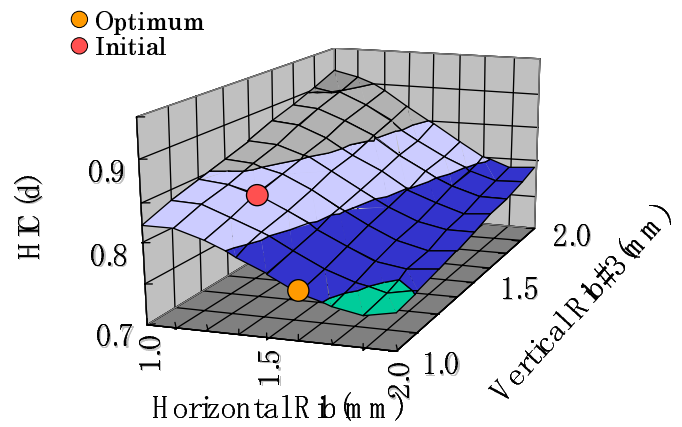


Fig. 9 Response surface (#3)

Deterministic FE analysis HIC(d) with the nominal input data after optimization is reduced to 0.713. Average and nominal variations of FE model after optimization are 0.868 and 0.039 evaluated again by the system shown in Fig.3.

Minimizing nominal HIC(d) by selecting thickness of four ribs reduced average of HIC(d), but increased nominal variation of HIC(d) from 0.039 to 0.041 (Table 2).

Table 2 Nominal minimum result

	Horizontal rib thickness (mm)	Vertical rib #1 thickness (mm)	Vertical rib #2 thickness (mm)	Vertical rib #3 thickness (mm)	Nominal HIC(d)	Average HIC(d)	Nominal Variation of HIC(d)
Initial	1.2	1.2	1.2	1.2	0.842	0.868	0.039
Nominal Minimum	1.6	1	1.6	1	0.713	0.733	0.041

If the nominal variation of HIC(d) were increased, repeatability in the actual tests would be less. Minimizing the nominal HIC(d) does not always maximize the possibility of achieving design target. Average and nominal variation of HIC(d) should be simultaneously minimized in order to sustain the repeatability of HIC(d) in the actual tests

OPTIMIZATION OF AVERAGE AND NOMINAL VARIATION OF HIC(d)

Optimizing two parameters such as average and nominal variation simultaneously is not so simple that the authors assumed that optimizing average and nominal variation are equivalent to maximizing following reliability coefficient Z_c (Equation 2, Fig. 10).

$$Z_c = (\text{Design target} - \mu) / \sigma \quad (2)$$

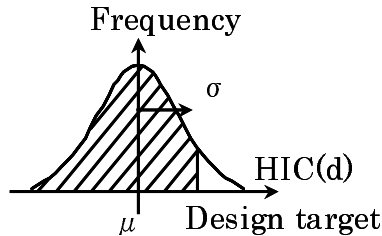


Fig. 10 Schematic chart of Z_c

A PALATE curve of average and nominal variation of HIC(d) is necessary to confirm maximum value of the reliability coefficient Z_c . Deriving a precise palate curve will need so numerous sampling calculations of impact FE analysis that the authors derived it by approximation method as follows.

At first, more than a thousand of perturbed combinations of design variables are sampled. Also more than a thousand of perturbed combinations of the boundary conditions are sampled for each sampled combinations of design variables. The sampled combinations of design variables and the boundary conditions are substituted into the response surface in Equation 2 and numerous combinations of HIC(d)s are calculated approximately by this equation. These results are summarized and average, nominal variation of HIC(d), and reliability coefficient Z_c are evaluated approximately for each sampled combination of design variables.

Next, approximately evaluated values of Z_c are sorted by average of HIC(d) (Table 3). The approximately evaluated values of Z_c are plotted as a function of average (Fig. 11). Boundary of feasible zone in Fig. 11 is a palate curve of average and nominal variation of HIC(d).

Table 3 Average and Nominal variation relation

	Horizontal rib thickness (mm)	Vertical rib #1 thickness (mm)	Vertical rib #2 thickness (mm)	Vertical rib #3 thickness (mm)	Average	Nominal Variation	Z_c
1	2	1.5	2	2	0.721	0.445	1.761
2	2	1.5	2	2	0.721	0.445	1.761
3	2	1.5	2	2	0.722	0.442	1.759
4	2	1.49	2	2	0.722	0.442	1.76
5	2	1.52	2	1.95	0.724	0.443	1.75
6	2	1.5	2	1.9	0.726	0.422	1.748
7	2	1.45	2	1.86	0.727	0.416	1.749
8	2	1.45	2	1.85	0.727	0.413	1.748
9	2	1.43	2	1.79	0.73	0.4	1.746
continued	continued	continued	continued	continued	continued	continued	continued

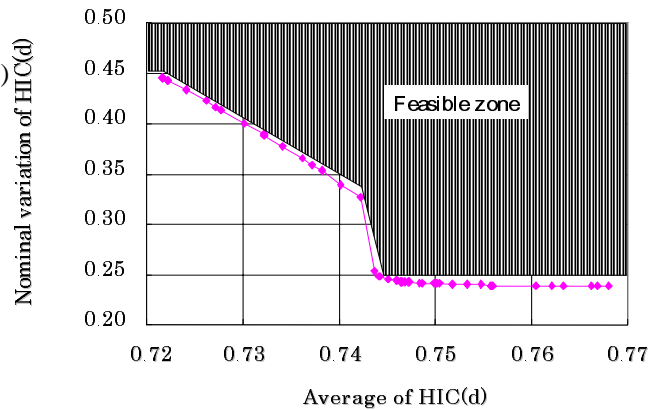


Fig. 11 Relation of nominal variation and average of HIC(d)

Judging from the palate curve in Fig. 11, the maximum Z_c is 1.761, while vertical rib thickness is 1.9 mm, vertical rib #1 thickness is 1.2 mm, vertical rib #2 thickness is 1.6 mm, and vertical rib #3 thickness is 1.0 mm. The FE model was modified to the thickness maximizing reliability coefficient Z_c . Average and nominal variation of HIC(d) are evaluated by the process shown in Fig. 3. Nominal HIC(d) is 0.722, average of HIC(d) is 0.738, and nominal variation of HIC(d) is 0.035 (Table 4).

Table 4 Z_c maximum result

	Horizontal rib thickness (mm)	Vertical rib #1 thickness (mm)	Vertical rib #2 thickness (mm)	Vertical rib #3 thickness (mm)	Nominal HIC(d)	Average HIC(d)	Nominal Variation of HIC(d)
Initial	1.2	1.2	1.2	1.2	0.842	0.868	0.039
Nominal Minimum	1.6	1	1.6	1	0.713	0.733	0.041
Z_c maximum	1.9	1.2	1.6	1	0.722	0.738	0.035

DISCUSSION

Nominal minimum FE model indicates the least average of HIC(d) among the three cases. Z_c maximum FE model indicates the least nominal variation of HIC(d) among the three cases (Table 4).

Theoretical three sigma distribution range of HIC(d) of nominal minimum FE model is from 0.610 to 0.856. Theoretical three sigma distribution range of HIC(d) of Z_c maximum FE model is from 0.633 to 0.843. In case that the design target is 0.850, nominal minimum FE model indicate HIC(d) may exceed the design target and Z_c maximum FE model indicate HIC(d) may not exceed the design target, although nominal minimum FE model indicate lower average HIC(d) than Z_c maximum FE model.

As described here, probability of achieving design target depends not only average of HIC(d) but also nominal variation of HIC(d). Optimizing average of HIC(d) and nominal variation of HIC(d) simultaneously is important for increasing probability of achieving design target.

CONCLUSIONS

A method for optimizing average and nominal variation of HIC(d) simultaneously was developed by newly introduced reliability coefficient.

Optimizing average and nominal variation of HIC(d) by this method indicates bigger probability of achieving design target than optimizing by traditional nominal minimum method.

ACKNOWLEDGMENT

The authors wish to express their acknowledgements to Mr. Kenshi Tomiki for his sampling input data by Latin Hyper Cube method.

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